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Rheological Characterization of Biomass Feedstock for Alternative Energy Applications

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Abstract

With the increased necessity of alternative energy resources, bulk feedstock biomass materials were characterized with the purpose of replacing depleting energy supplies such as fossil fuels and other nonrenewable energy sources. Residual organic waste material (biomass) left over from agricultural processing and handling systems was recycled, and further investigated for renewable energy use. Understanding the scope of flowability for biomass material yielded more efficient, and economical crop harvesting, transporting, and storing method design for the agricultural industry. The effects of moisture on bulk solid flowability was investigated using a variety of parametric testing methods that measure basic flowability energy, and other properties such as compressibility and material resistance. In an industry where organic material is a wasteful byproduct, converting this biomass material into a new energy source and streamlining efficiently for innovative agricultural development supports a clean, renewable energy approach to everyday nonrenewable energy uses, such as oil, propane, and coal. As observed from the repeatable results from the investigated rheological material properties, biomass is an incredibly diverse material that requires modern engineering solutions to revolutionize biomass into a renewable energy source. Biomass will decarbonize petroleum (nonrenewable) derived fuels and chemicals, yielding recyclable carbon. This push to replace fossil fuels with recycled carbon is ideal because of the abundant, renewable, and otherwise agricultural waste of corn stover material. Decarburization, and reduction of C02 emissions reduces the effects of global warming.

Rheological Characterization of Biomass Feedstock for Alternative Energy Applications

Introduction

Renewable energy solutions for alternative energy applications requires the innovation and advancement between automation processing and systems operations. With new robotic samplers, all disciplines of research and design have benefitted from high speed, high efficiency data collection. Specifically within the realm of biomass and green energy production, robotic processing and sampling is the future of quality, reproducible data collection. Processing bulk solids such as organic biomass material was investigated using a Freeman Technology Powder Rheometer (FT4), where the thermal and rheological properties of corn stover were tested and analyzed. The objectives of this project is to understand the relationship of moisture (a critical material attribute) to the operational reliability of bulk solids handling and transport. Understanding and mitigating the impacts of moisture content for integrated biorefineries offers an improved economic pathway in biomass handling, transport and conversion. With the introduction of moisture in biomass feedstock, the aim of understanding the change in material properties with moisture was essential when researching the flow rates and economically viable solutions of bulk solids handling and transport. Further thermal analysis of material crystallinity, crosslinking, and overall material structure when subjected to cycles of heating/cooling was essential when observing the endothermic and exothermic behaviors of biomass materials, further limiting methods of material storage, handling, and processing. This ongoing study of recycling biomass material into useful renewable energy sources will mitigate the effects of global warming by developing and switching to cleaner fuel resources.

Project Description

Using an FT4 Powder Rheometer, a powdered low ash corn stover biomass material was tested and observed with respect to flow energies, compressibility, permeability, shear strength, and wall friction strength. Creating 0%, 25%, 50%, and 75% moisture/low ash samples, this resulted in a comparable display of biomass material properties in response to each respective test. In order to quantize flowability, and basic flowability energy of a powder material, methodologies for testing stability and variability flow rate, aeration, compression, permeability, shear strength, and wall friction parameters were created, and data was collected respectively. Despite the challenges that moisture introduces into processing equipment of bulk solids, the continued characterization of the rheological behavior of corn stover will yield less equipment clogging, and lower operational costs. With new strategies of how to transport and process bulk solids, the measured flowability behavior of corn stover will be critical when redesigning storage and handling equipment to mitigate the impact of moisture on biomass materials in the agricultural industry. Six rheological tests were conducted using the Freeman Technology Powder Rheometer. These bulk, dynamic, and shear testing methods were analyzed within the scope of modernizing bulk processing methods, as well as decarbonizing petroleum derived fuels and chemicals. As seen in Figure 1, the basic flowability energy was analyzed with respect to moisture content. With the stability and variability testing method, 11 cycles of conditioning and testing was preformed using a rotating metal blade. The resulting flow energy was measured by the amount of work required to turn and move the blade through the length of the testing vessel. Next the dependency of flow energy on blade speed was measured as seen in Figure 2. Test cycles # 9-11 varied in blade speed (70, 40, and 10 mm/s respectively).

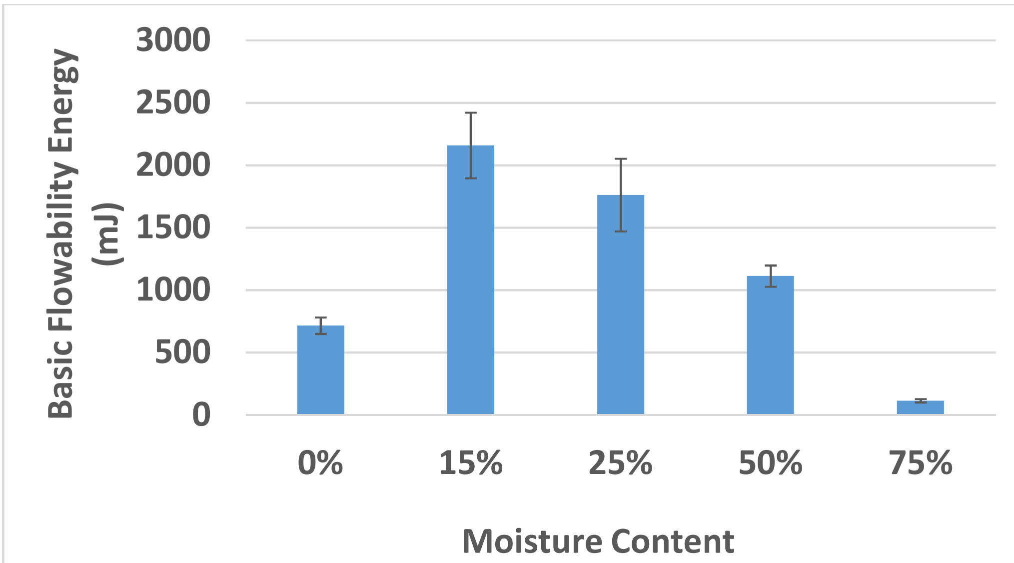

Figure 1: Basic flowability energy (BFE) with respect to moisture content

From the data collect, the 15% moisture sample required the most amount of energy to move the blade though the powder. From 0%-15% moisture yielded an increasing amount of energy needed to turn the blade. From Figure 1, the maximum BFE occurred at the 15% moisture sample, resulting in the most work required to move the sample. Inversely, from 15% to 75% moisture samples, the average total energy decreased, with 75% moisture being the most optimal wettability to transport the material.

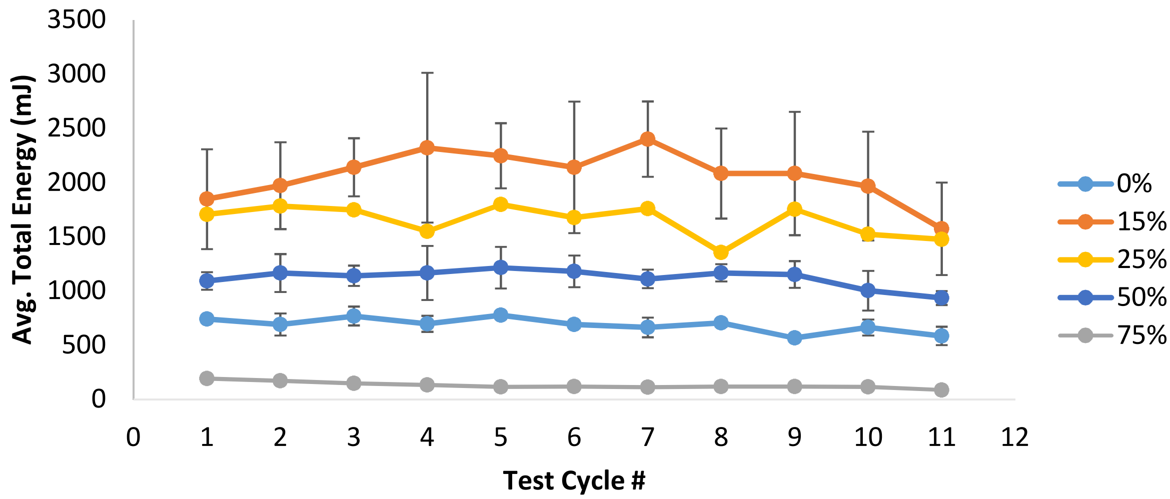

Figure 2: Stability and variability flow rate total energy based on blade speed

As observed from Figure 2, the 11^{th} test cycle, with a blade speed of 10mm/s resulted in the lowest average total energy needed to move the blade through the powder. In accordance with Figure 1, the 75% moisture content sample resulted in the lease average total energy needed to move the blade through the sample. Furthermore, the 75% moisture sample showed the lowest variance in standard error of those samples tested. Next utilizing the compressibility testing method, a vented piston compressed the samples under increasing normal stresses. This yields the % volume deduction of each sample, which was then used to calculate the % compressibility using the initial and final volume.

$$\%\, Compressibility = \frac{V_0 - V}{V} \times 100\% \qquad \text{Eq. 1}$$

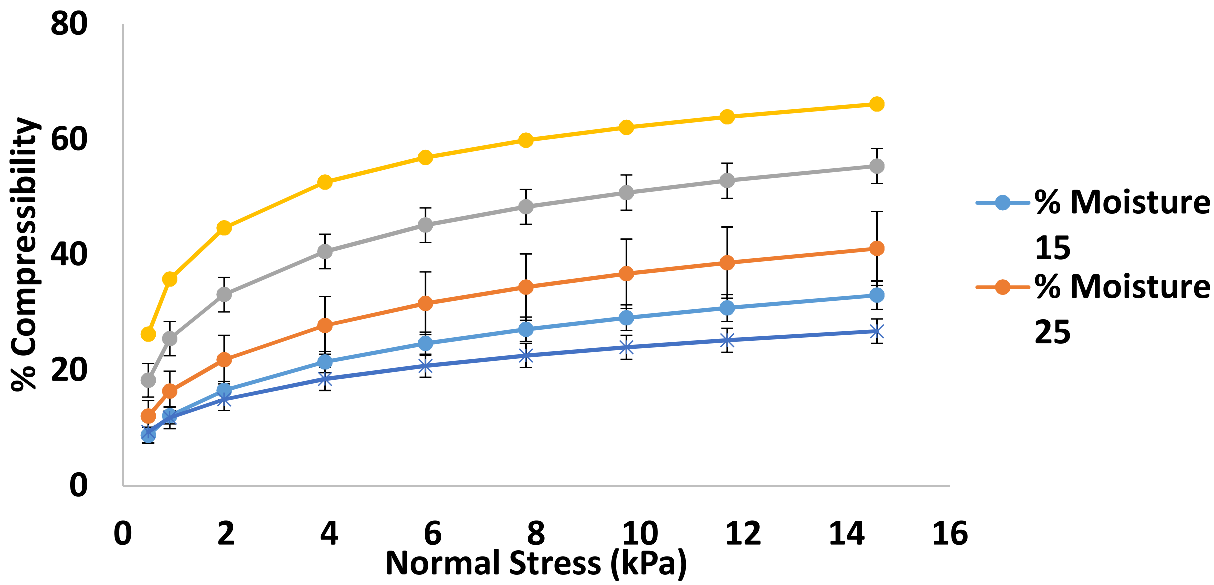

Figure 3: Compressibility with respect to normal stress

As observed from Figure 3, the 75% moisture sample was the most compressible. The trend further relates how the increased normal stress resulted in a greater % compressibility, slowly increasing to a max point. The greater compressibility of the 75% moisture content sample is due to the larger clumps that form with increased moisture, creating a looser natural packing of the powder material, and greater room for compression. Compatibility is a crucial material property as materials storage in silos compacts the bottom layer of material, compressing and plugging machinery. Understanding the repercussions of compressing material yields modern day designs of silos that avoids damaging material and store equipment. The next testing method utilized in the characterization of low ash corn stover collected data of the wall friction between the sample and testing vessel. The wall friction testing method consists of conditioning and compressing the sample with various levels of applied normal stress with a shear disk attachment, rotating and shearing the material. Two types of material were used to shear the material, PTFE and Stainless

Steel. With these materials, amount of friction between the corn stover and vessel wall was measured.

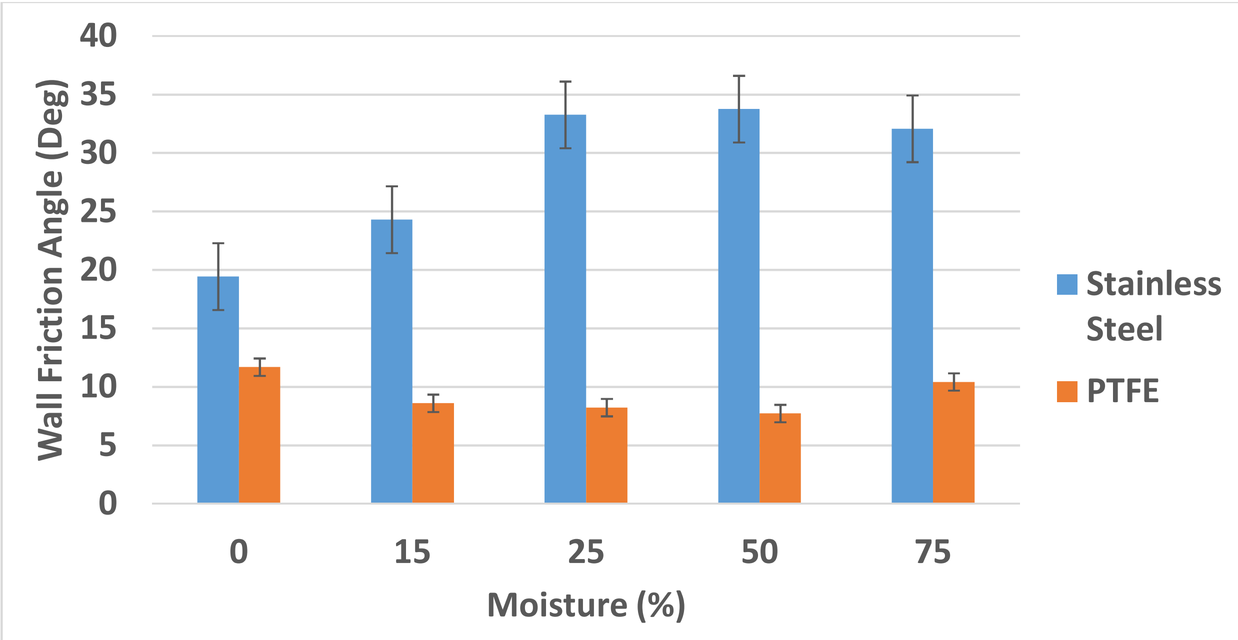

Figure 4: Wall friction angle with respect to moisture content

With wall friction angle (WFA) testing, the material with the lowest angle is more ideal (indicating no friction is present between the sample and material). Using the material that causes the least amount of friction reduces handling and transporting costs, increases efficiency, and modernizes new hopper, baler, and other agricultural industrial equipment. As seen from Figure 4, Observing the stainless steel and PTFE disks used, the PTFE disk first had a wall friction angle that decreased, plateaued after 15% moisture, and then increased at 75% moisture content. The hydrophobic PTFE disk surface causes a layer of moisture to stick between the disk and powder, causing increased lubrication, and decreased friction. This information is crucial when choosing a material for bulk handling, understanding the rheological characterization of the interacting materials dictates the efficiency of transportation.

Combining Figure 1 and Figure 2 reflecting the stability and variability testing results, the most efficient moisture content was the 75% moisture.

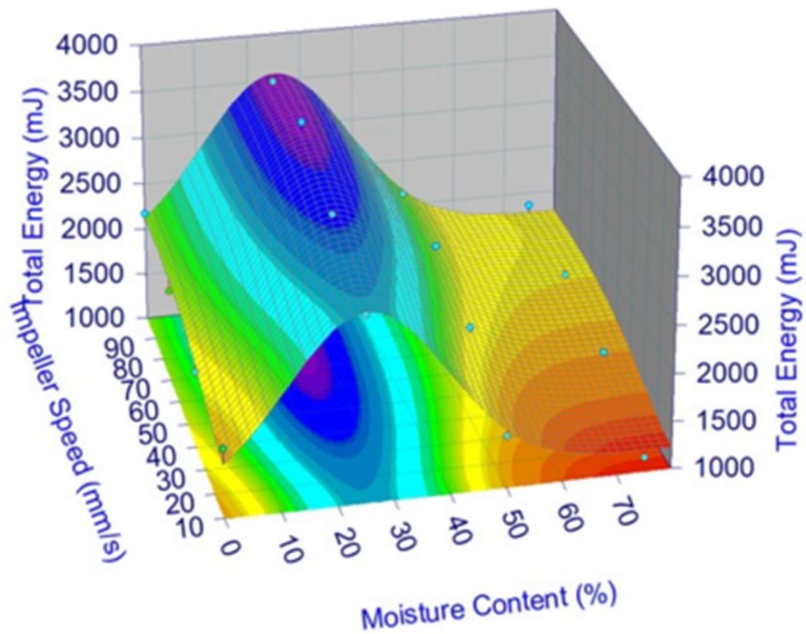

Figure 5: stability and variability of moisture content with respect to total energy and impeller (blade) speed

With the observed results that drying biomass corn stover material is most energy, time, and money effective when only dried to 75% moisture greatly reduces the cost, time, and energy of over drying biomass material and obtaining a material that is more difficult to handle and process.

Contributions

Hundreds of corn stover samples were tested with many different methods and machinery, such as the FT4 Powder Rheometer, Differential Scanning Calorimeter (DSC), TrippleFlex, ADD OTHER MACHINES. Characteristics such as surface area of particles, and surface energy was measured and observed using techniques of inverse gas chromatography. A variety of stove samples were tested, including cob, stalk, husk, low ash, and high ash moisture samples. Samples were continuously tested and observed, adjusting testing methods accordingly. With the lack iof reproducibility, and often times error ridden data taken from the FT4 wall friction testing, a new testing vessel was designed, and 3D printed to improve data collection methods. (INSERT CAD DRAWING FILE). Weekly team updates were used to encourage communication within the project, as well as ensure effective data collection. With this work, this data collected will be used in an upcoming publication, laying the groundwork for the necessity of biofuel products, as well as modern agricultural handling machinery design for hoppers, silos, and balers.

Skills and Knowledge Gained

Spanning the 10 week internship opportunity at Los Alamos National Laboratory data collection, analysis, and presentation was practiced and applied to the study of biomass materials to further develop renewable and alternative energy solutions. Various biomass material properties were analyzed using a variety of automated processing and sampling methods. First, a differential scanning calorimeter (DSC) automated sampler was use for thermal analysis on many biomass samples. Sample method design techniques were utilized to test samples with cycles of heating and cooling, where endothermic and exothermic behaviors were observed. Powder rheometry was further investigated, testing biomass material under shear, compression, aeration, stability, and variability testing methods. Testing methods were developed and improved to yield the most reproducible, low error data. Analyzing data from a reproducible standpoint was an invaluable skill that I learned. Further techniques of displaying data from a scientific mindset in a clear, concise, and understandable manner to communities outside of the STEM community proved invaluable for ongoing and future presentations and projects. Working in a professional laboratory environment exposed the significance and importance of safety and communication that is mandatory when working in a group setting. Finally, with the participation in the 2021 Student Symposium, I learned the importance of communication and related the significance, relevance, and results of research projects to both the scientific and nonscientific communities. Lastly, the many educational lecture series at LANL provided extremely valuable information not only on how to operate in a professional setting as a student intern, but also provided an outlook on the various fields of STEM that LANL supports, and further career options and advice.

Benefits to Education and Professional Development

Further researching and developing alternative energy solutions to aid in the decarbonization of the atmosphere is crucial to the continued security and prosperity of the United States of America. With depleting nonrenewable energy sources costing the United States billions each year, in house production of recycled biofuel materials such as corn stover would provide unlimited potential and renovation, of the earth’s atmosphere and the carbon footprint of the scientific community. Developing and curating clean energy sources provides clear leadership and an united goal of maintaining earth's atmosphere while supporting and cultivating innovative scientific solutions to crucial, life threatening global challenges.

Academic and Career Planning

The further study, investigation, and exposure into the realm of biomass energy applications has encouraged me to continue my research in alternative energy resources. Continuing this research will have a profound impact on many ongoing research and design developments in terms of biomass handling and processing, as well as positively impact the environment by reducing C02 emissions. With this ongoing research, I will be contributing to a future publication that will share our scientific research with a greater scientific community and lead to many future developments. Creating new reusable energy sources from recycled carbon is a topic that I am passionate about, and feel strongly I am making a positive impact on the global health of the planet. Furthermore, I hope to continue my education after completing my bachelor's degree in an energy engineering related field.

Acknowledgements

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